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THE CROWSNEST VOLCANICS

by

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By J. D. MacKenzie.

INTRODUCTION.

GENERAL STATEMENT.

The Crowsnest volcanics are a series of tuffs and agglomerates, with exceptionally occurring flow rocks, that are found in the eastern Rocky mountains of Alberta, in the general vicinity of the Crowsnest pass.

During the summer of 1912, the writer was engaged in the geologic mapping of the southern extension of the Frank-Blairmore-Coleman coal fields, in southwest Alberta, and had frequent opportunities to study the field relations of these volcanics. Specimens of the more typical varieties of the rocks were collected, and have since been studied petrographically, the results forming a part of this paper.

Personal observation has been confined to the valley of the Southfork river and adjacent exposures, and visits to some outcrops on York creek, near Blairmore. The following observations and remarks thus apply more particularly to the southern exposures of the formation; but descriptions of the more northern occurrences by Leach and Dawson show that the characteristics of the volcanics are essentially as described below. Owing to the press of other matters in the field not as much time could be devoted to the study of these pyroclastic rocks as is desirable, but the facts that have been gained are perhaps deserving of record at this time, though the formation would repay a more detailed and careful study.

In the preparation of this paper the writer was helped by advice and criticism from the late W. W. Leach, and from Dr. C. H. Warren and Dr. H. W. Shimer. The work in connexion with this paper was prepared in the geological laboratories of the Massachusetts Institute of Technology.

HISTORICAL.

In 1886 G. M. Dawson published some brief descriptions of these volcanics, and listed some localities where he had observed them.[1] He states (p. 69 B) that they were first observed in 1881 (by himself ?) in the Crowsnest pass. In 1902 W. W. Leach of the Geological Survey of Canada mapped and made a report on the Blairmore-Frank coal fields.[2] He makes note of the usefulness of the volcanics as a horizon marker. Specimens of the tuffs and agglomerates collected by Mr. Leach have been examined petrographically by C. W. Knight[3] and further reference will be made to his work. Leach, in his detailed examination, in 1912, of the Blairmore map-area, gives measurements of the volcanics.[4]

So far as is known to the present writer, the references noted above form the only literature in regard to these rocks published to date.

LOCATION.

The district underlain by the Crowsnest volcanics comprises a portion of the eastern Rocky mountains and their foothills, in southwest Alberta. The southernmost outcrops are in about latitude 49°25′ north, and they extend nearly due north some forty-eight miles to about latitude 50°05′ north. The southern boundary of the formation is not far south of the South Branch

[1]Dawson, G. M., Geol. and Nat. Hist. Survey of Canada, Part B, Ann. Rept., 1885, pp. 57B, 69B, 88B.

[2]Leach, W. W., Ann. Rept., Geol. Survey, Canada, vol. XV, p. 171 A.

[3]Knight, C. W.. Canadian Record of Science, Montreal, vol. 9, No. 5, 1905 pp. 265–278.

[4]Leach, W. W., Summary Rept. Geol. Survey, Canada, 1911, p. 197.

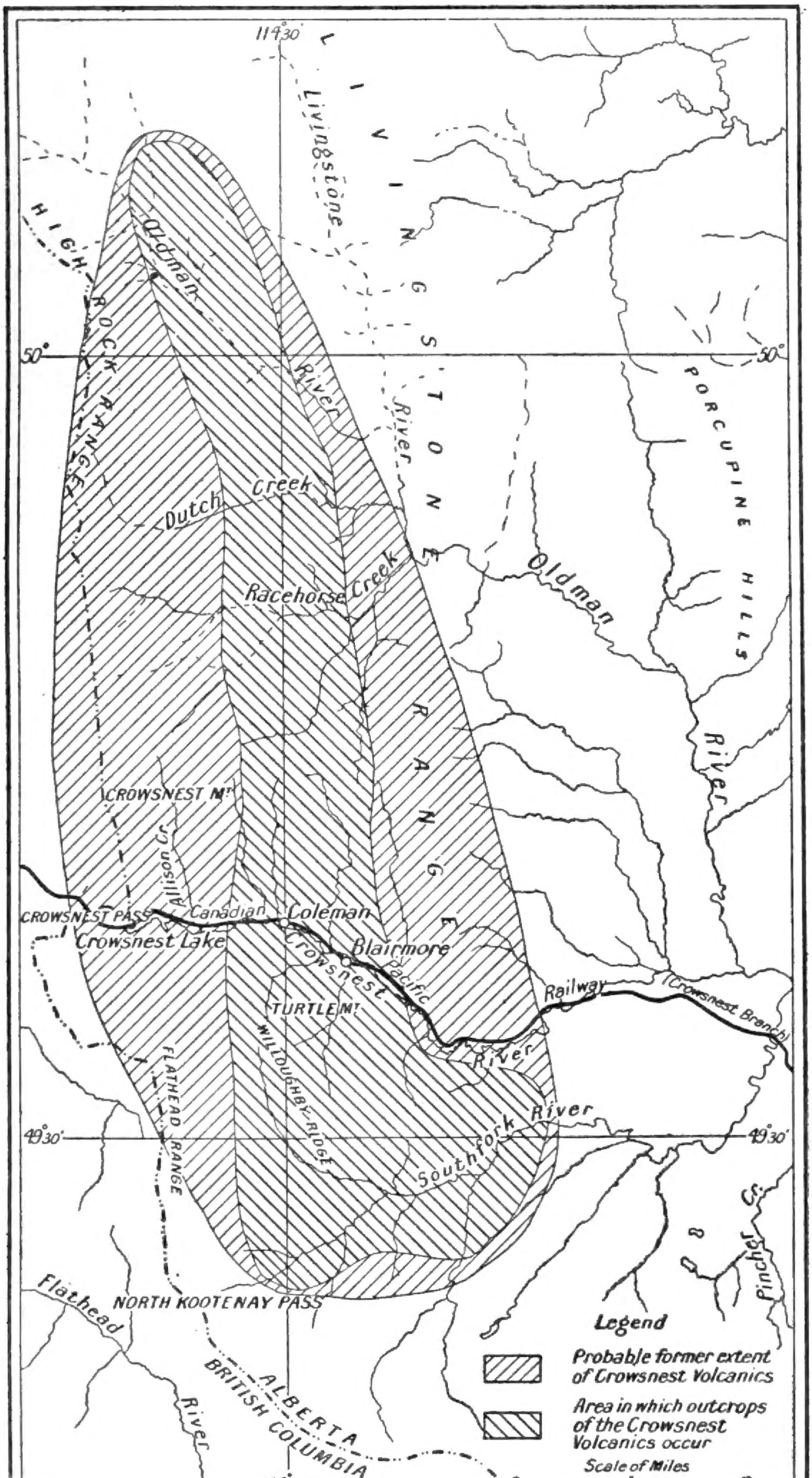


Figure 1. Diagram showing location of the Crowsnest volcanics.

South Fork Oldman river (commonly called the Southfork river), and the most northern outcrops noted by Dawson are on the Northwest Branch North Fork Oldman river. On the Southfork river, the width of the area underlain by these rocks is some fourteen miles; this width narrowing somewhat to the north, where the volcanic area lies wholly between the Livingstone range on the east, and the main range of the Rockies on the west. The area in which outcrops occur at the present time is about 500 square miles, and from considerations to be mentioned later (see p. 10) it is thought that a somewhat larger area was originally subjected to the deposition of the volcanic material.

The most accessible outcrops of these tuffs at the present time are on York creek, about two miles west of Blairmore, Alberta, where several varieties may be seen; and about a mile west of Coleman, Alberta, where other very massive types are well exposed on the main highway through the pass.

GENERAL GEOLOGY.

STRATIGRAPHY OF THE CROWSNEST VOLCANICS.

Stratigraphic Position.

The stratigraphic position of the volcanics is shown in the following section of the measures in the eastern foothills where the volcanics are found.

Superficial Deposits.

Pleistocene and Recent.

(*Unconformity*)

Allison formation (Belly River)....	+2000 ft.[1]	Upper Cretaceous
Benton formation................	2700 "	
CROWSNEST VOLCANICS............	0–1150 "	
Dakota(?) formation.............	2500 "	
Kootenay formation..............	600 "	Lower Cretaceous.
Fernie formation.................	600 "	Jurassic

[1]Thicknesses approximate.

(*Disconformity?*)

Turtle Mountain Group.......... Devonian and Carboniferous

This section is conformable throughout, with perhaps a slight disconformity at the base of the Dakota, indicated by a very persistent twenty-five foot bed of cherty conglomerate.

The beds of the Turtle Mountain group are light to dark grey, massive cherty limestones; the Fernie and the lower Kootenay are dark grey to black carbonaceous shales, and the upper Kootenay is composed of more arenaceous beds with several coal seams, which are extensively mined in the Crowsnest pass. The Dakota beds are mostly fine to medium quartzose sandstones of a striking green colour, alternating with more shaly beds. Near the top are several bands of soft, bright red ferruginous clay shales. The Benton measures are almost wholly fine-grained, dark grey fissile clay shales, and the Allison beds are typically soft, light grey, cross-bedded sandstones.

For further information in regard to the stratigraphy and structure of this region see the reports already referred to and also the Summary Report of the Geological Survey of Canada for 1912.[1]

Relations to the Underlying Dakota.

The contact between the upper Dakota measures and the volcanic rocks is a gradational one. On approaching the horizon of the volcanics the Dakota beds as a rule become coarser, and distinctly tufaceous material becomes noticeable. The beds often pass gradually from greenish sandstones and shales into well stratified tufaceous rocks, and the exact contact can often not be placed at any given horizon.

The character of the sediments at the top of the Dakota indicates shallow fresh-water or terrestrial conditions. Layers of bright claret coloured ferruginous shales are common, and mudcracks and rather indistinct ripple-marks have been observed.

[1]MacKenzie, J. D., Summary Rept. Geol. Survey, Canada, 1912, pp. 235–246.

It is worthy of note that a thin bed of tuff occurs interstratified in the Dakota, near the middle of the formation on Ma butte, northeast of Crowsnest mountain.[1] The following section across the lower beds of the volcanics was observed on Jackson creek, in the Southfork valley.

Measures	*Thickness*
Massive beds of coarsely fragmental agglomerate.	
Coarsely fragmental orthoclase agglomerate.	10 ft.
Black carbonaceous seam, full of rounded sand grains but clearly of a coaly nature.[2]	4 in. to 8 in.
Hard, light purplish tuff.	0 ft. 8 in.
Soft green, fine-grained tuff.	2 ft. 0 in.
Hard, coarse to medium, dark green tuff, fragmental orthoclase up to ½ inch.	8 ft. 0 in.

Conformable on fine, dark green (tufaceous) sandstones of the upper Dakota.

Relations of the Volcanics to the overlying Benton.

Here again is a gradational relationship. Owing to the soft character of the Benton shales this contact is usually obscured by detritus, and was only actually observed in one locality, where a prospect trench had been dug across it; but as the volcanics are usually finer and thinner bedded toward the top, the transitional relationship had been inferred before it was actually seen. The trench above mentioned is on the south bank of the Southfork river, just below the junction of its west and south branches. The following section was observed, in descending order:—

[1]Leach, W. W., Summ Rept. Geol. Survey, Canada, 1911, p. 196.

[2]This is the only occurrence of the kind noted by the writer. Dawson speaks of having seen plant remains in the volcanics elsewhere in the Southfork valley.

Dawson, G. M. Ann. Rept. Geol. Survey, Canada, 1885, Part B, p. 57B.

Measures	*Thickness*	*Formation*
Dark grey, fissile shales	....	Benton
Dark bluish grey, very hard, cherty conglomerate, with rounded pebbles up to 1 inch, in a siliceous matrix	1 ft. 6. in.	
Concealed	4 ft.	
Conglomerate similar to above	0 ft. 10 in.	
Dark greenish grey concentric weathering fine clay shale	0 ft. 10 in.	

Below here the beds, though fine grained and well stratified, are of a tufaceous appearance, and are to be classed with the volcanics. The contact is perfectly conformable and gradational, but is best placed at this horizon where distinctly tufaceous material begins.

Measures	*Thickness*	*Formation*
Dark green homogeneous, coarse tufaceous shales	0 ft. 7 in.	Crowsnest volcanics
Dark green, concentric weathering fine clay shale	0 ft. 6 in.	"
Greenish, weathered, soft, angularly fragmental, medium-grained tuff	0 ft. 6. in.	"
Light rusty-greenish, fine-grained tuff	3 ft. 0 in.	"
Purplish green, soft tuff, not all exposed	2 ft. 0 in.	"
Concealed	5 ft.	"
Dark greyish green, fine, hard, compact tuff	2 ft. 0 in	"
Green, rusty weathering, fine tuffs	3 ft. 0 in.	"
Dark greenish, medium-grained, laminated tuffs	5 ft.	"
Concealed below here		
Benton exposed	7 ft. 2 in.	
Tuffs exposed	27 ft. 7 in.	
Total section	34 ft. 9 in.	

Similar sections are to be seen in the South Branch Southfork river, within a half mile west of here, where the beds are repeated by folding.

It has been noted that the Benton measures are virtually, wholly fine shales, indicating deep water conditions, while the Dakota beds are characteristic of more shallow zones of sedimentation. This relationship indicates a considerable and immediate subsidence after the volcanic activity in the region, and in fact even during the period of eruptions. The association of volcanic action with a sinking terrane is mentioned by Geikie.[1]

Internal Stratigraphy and Structure.

The volcanics as a whole are thoroughly stratified and, in nearly all cases, clearly water laid deposits. Thin beds are the rule, and it is rare that individual strata over ten feet thick are found. Irregular bedding is not uncommon. Layers of fine-grained, highly feldspathic tuffs are frequently seen near the base, and are scarcely to be distinguished from sandstones in the field. Some of these finer and more homogeneous tuffs are so dense and hard that they outwardly resemble lavas. Many varieties of tuff and agglomerate are present, from the types just mentioned, composed of angular fragments of feldspar in a finer ash matrix, to very coarse heterogeneous breccias of explosive ejecta. Some beds are characterized by rectangular crystals of red and white or glassy feldspar up to an inch in size, embedded in a more or less homogeneous fine tufaceous matrix, and these rocks are easily confused with porphyries in the field. Again, distinctly water worn pebbles of varying sizes and proportions occur in a tuff matrix and these by increasing size of fragments pass into agglomerates. No regularity in regard to sequence of strata has been observed in different repeated sections of the volcanics, and it is evident that the various beds are of a

[1]Geikie, Archibald. Volcanoes of Great Britain, vol. 2, p. 470.
He concludes his remarks by saying,"........there can be no question that with the one solitary exception of the Tertiary volcanoes, which were terrestrial and not submarine, all the British vents were carried down and eventually buried under aqueous sediments. Even the Tertiary lava fields have in many cases sunk down below sea level since their eruptions ceased.''

lenticular nature. Ellipsoidal lavas (pillow lavas) or amygdaloids have not been recognized. Indeed, lava flows or injected volcanic rocks are of very exceptional occurrence. The late W. W. Leach in a personal communication stated that he had seen evidences of small flows a short distance north of the town of Coleman, and also on Ma butte, northeast of Crowsnest mountain.

Thickness and Volume.

The maximum thickness of the volcanics seen by the writer is about 1000 feet. Leach[1] gives the thickness west of Coleman as 1150 feet, and states that "It appears that the volcanics reach their greatest thickness about two miles east of Crowsnest mountain, thinning out rapidly to the eastward." This maximum observed thickness occurs in the westernmost band of tuffs that are exposed. West of this band, the rocks are of the overlying Benton and Allison formations until the great overthrust bringing up the Palæozoic measures on top of the Cretaceous is reached. There is no good reason for supposing that the former areal extent of the volcanics was not greater in a westerly direction, and that they are not now concealed on account of the overthrusting. It is possible that the greatest observed thickness of 1150 feet is not the true maximum for the tuffs, and they may have been thicker to the westward. The horizon of these rocks is not exposed in the Crowsnest basin to the west, so definite data is lacking as to their extension in that direction. However, it is the writer's opinion, and with this statement Mr. Leach agreed, that the former extension was not over ten miles west of Crowsnest mountain, and that their maximum thickness is not far from that observed. In any event, they show a constant decrease in thickness from the vicinity of Crowsnest mountain towards the north, south, and more rapidly, towards the east.

The total present areal extent of the volcanics as represented on Dawson's map of the Rocky mountains,[2] and on Leach's

[1]Leach, W. W. Summ. Rept. Geol. Survey, Canada, 1911, p. 197.

[2]Accompanying Part B, Ann. Rept. Geol. Survey, Canada, 1885.

map of the Blairmore-Frank Coal Fields,[1] supplemented by data obtained by the writer in the country south of that shown on Leach's map, is about 550 square miles. Shortening of the width of the formation due to faulting has been allowed for when information in regard to it was available.

Supposing a former extension westward of ten miles beyond their present width, the area originally subjected to the deposition of volcanic sediment may be conservatively placed at 700 square miles, with a maximum length of fifty miles from north to south, and a width of about fifteen miles. Assigning a maximum thickness to the formation of 1000 feet (a moderate estimate) and supposing them to thin out gradually to nothing towards the north, south, and east (neglecting for a moment their probable former extension westward from the longitude of the Crowsnest mountain) we arrive at a volume for the volcanics of about thirty-five cubic miles. The inferred westward extension of the formation is wholly uncertain as regards quantitative data, but it seems probable that there should be assigned a total volume for the volcanics of about fifty cubic miles.

Conditions of Deposition.

Summary.

It is evident from the stratified nature of the deposits, and their conformability with and gradation into both the underlying Dakota and the superincumbent Benton that the volcanics are very largely of subaqueous origin. Furthermore, the large number of water worn fragments of considerable size in many beds, the frequent false bedding, and the occurrence of coal in at least one locality indicate that the formation was largely deposited in shallow water. The unsorted character of numerous individual layers, and their lenticular nature supports the same conclusion; and it is possible that some beds are subaërial in origin, laid down where transporting and classifying currents did not sort the material.

[1]Accompanying Part A, Ann. Rept. Geol. Survey, Canada, vol. XV, 1903.

Conditions Preceding Eruption.

During the late Jurassic, Lower Cretaceous, and early Upper Cretaceous periods, this area was the scene of sedimentation of an extensive scale, forming part of the great Rocky Mountain geosynclinal prism. Immediately preceding the volcanic out-burst, 2,500 feet of Dakota measures had been accumulated. In general, they were laid down in relatively shallow water, and the red beds, ripple marks, and mud-cracks near the top of the formation indicate terrestrial and probably fresh-water conditions at the time immediately preceding the volcanic eruptions. The occurrence of thin tuff beds within the Dakota formation shows that the approach of the main period of vulcanism was heralded by minor out-bursts at an earlier date.

Probable Magnitude of Eruptions.

It has been shown that volcanic ejecta accumulated to a maximum depth of at least 1,000 feet and occupied an area of 700 square miles, and it is interesting to compare the scale of this out-burst with some of those in historic times.

Martin,[1] in his description of the eruption of Mount Katmai, Alaska, gives some facts regarding modern volcanic explosions. He states that dust from Krakatoa fell to a depth of eighteen inches in twenty-four hours at a distance of sixty-six miles, and the depth of ash from Katmai was about twelve inches at a distance of 100 miles. Tomboro, on the island of Sumbawa, east of Java, caused the accumulation of over two feet of ash more than 850 miles from the scene of eruption. These distances are all greater than the total length of the area over which the Crowsnest volcano distributed material, supposing it to occur at one end of the volcanic area, which it very probably did not. On the other hand, the sizes of the material at present composing the Crowsnest volcanics are generally larger than "ash" or "dust." Fragments up to two feet in diameter have been seen and larger probably occur. In this connexion it may

[1]Martin, G. C. The Recent Eruption of Katmai Volcano in Alaska, National Geographic Magazine, vol. 24, 1913, pp. 131–181.

be noted that Martin (p. 174) speaks of a fragment the size of a brick having travelled through the air to a distance of fifteen miles from the volcano. Doubtless much of the finer ash and dust from the Crowsnest eruptions were carried out of the zone of deposition of larger fragments by air and water currents.

The volume of material ejected from Katmai is given (p. 167) as 4·9 cubic miles, extending over an area of many thousand square miles, as against the fifty cubic miles of the Crowsnest tuffs and breccias spread over 700 square miles. Tomboro is supposed by some (p. 165) to have ejected fifty cubic miles of material in a single eruption, again spread over thousands of square miles. A more conservative estimate gives twenty-eight cubic miles.

Even allowing for ash carried away by currents, it is not probable that a much greater area than is now represented by volcanic sediment was originally effected by the out-burst, but instead, it would appear that a large volume of material in comparison to the area involved, was deposited. The thinness of individual beds, and their alternation in character indicates that the formation was built up by successive eruptions none of which were of very great magnitude. The absence of flows or sills shows that the eruptions were dominantly of the explosive type.

It thus seems apparent that the individual eruptions were not of great violence, and that a preliminary explosion during Dakota time fore-shadowed the approach of the Crowsnest epoch, during which continual explosions on a moderate scale took place. The time of eruption was probably short, reasoning from the amount of material sent out during a single out-burst of modern volcanoes. The explosive period ceased abruptly, and was followed by a rather rapid subsidence, as has already been pointed out.

Location of Vents.

No recognizable volcanic vents have been observed in any of the outcrops studied. This is not altogether surprising when it is remembered that only a small portion of the formation is exposed at the surface, and of the exposed part, only occasional localities were visited. However, it has been stated that the greatest thickness of the beds is in the vicinity of the Crowsnest mountain, and also that it is probable that the thickness there is about the maximum, so that the main centre of eruption may safely be considered to have been in that vicinity. There is no evidence to show that there was more than one vent, unless the elongate form of the deposit may be considered as such. However, this may be due to current action in distributing the sediments and further and more detailed study might throw light on this subject.

It is the writer's opinion that there was a linear arrangement of several vents in a north and south direction about the meridian of Coleman, Alberta.[1]

Conclusions.

At the time when the deposition of the Crowsnest volcanics began, the area they now cover was occupied by a shallow sea probably of fresh water, containing low marshy islands. There is no recognized evidence to show whether the vents emptied into the air, or were submarine; any cones that may have been built up above sea-level would naturally be destroyed during the incursion of the sea in Benton time. The thickness of the deposits in relation to their lateral extent seems to indicate that the beds are due to the simultaneous effect of several small volcanoes of moderate activity, rather than to the action of one large vent. The eruptions were of the explosive type, unaccompanied by flows except very locally, and took place in continual sequence during a relatively short period of time. By far the greater part of the ejected material fell into the sea, and there was deposited in more or less well stratified beds.

[1]This statement was written in April 1913, and in September of the same year, Dr. C. H. Clapp informed the writer that he had found a probable volcanic neck at Coleman. It is not improbable that still others may be discovered.

PETROGRAPHY.

PRELIMINARY STATEMENT.

The following description of the petrography of the Crowsnest volcanics comprises: a summary of the results of the work done by C. W. Knight in describing these rocks; descriptions of the primary rock types found in the breccias by the present writer, with one analysis; descriptions of the present types of pyroclastic rocks noted; a discussion, summary, and conclusions in regard to the petrology of the volcanics.

SUMMARY OF KNIGHT'S RESULTS.

The specimens studied by Mr. Knight were collected in 1902 by Mr. W. W. Leach, and belong to the collection of the Geological Survey of Canada. He notes the following rock types:[1] augite trachyte, tinguaite, andesite, and analcite trachyte. The last type is represented by an analcite-orthoclase tuff, which he names blairmorite-tuff, after the town of Blairmore, Alberta, near where some outcrops of the rocks occur. He suggests the name *blairmorite* for a rock, the probable finding of which he predicts, and which will contain icositetrahedral phenocrysts of analcite. He also describes a rock fragment of this type consisting of (loc. cit. p. 275) "......phenocrysts of orthoclase and analcite less than 1 mm. in diameter set in a groundmass of feldspar laths (a few of which have the twinning lamellae of the plagioclases) and a few smaller analcites. Some titanite is also present..........".

The following minerals were noted by Knight in the specimens loc. cit. p. 207:—

"Orthoclase, sanidine, analcite, augite, ægerite-augite, ægirite, acmite, diopside, titanite, microcline, anorthoclase, andesine, nephelite, hornblende, apatite, biotite, garnet, magnetite, and various secondary minerals, such as chlorite, limonite, calcite, etc. Sodalite is probably present in small quantities,

[1]Knight, C. W. Can. Rec. Sci., Montreal, vol. 9, 1905, pp. 265–278.

and possibly leucite." He comments on the amount of analcite in the tuffs, and discusses the primary origin of the mineral. Analyses of analcite, and of blairmorite-tuff accompany his paper, and will be referred to later.

PRIMARY ROCK TYPES.

Introduction.

The mineral composition of a pyroclastic rock may or may not closely represent the composition of the pyrogenetic rock or magma from which it was derived. In proportion as the component minerals differ in specific gravity, original size, degree of comminution and reassortment, the resulting tuff or agglomerate will tend to differ from its parent magma. In drawing conclusions as to the constitution of a magma from its representation as tuffs or agglomerates, these and other facts should be borne in mind. Stress should be laid on primary rock types occurring as fragments in breccias, and on mineral associations constantly recurring in the clastic rocks. Occasionally pyroclastic rocks may simulate the appearance and composition of their parent pyrogenetic rocks very closely, and one or two instances of this kind have been noted in the present suite of specimens.

The primary rock types represented either by hand specimens of fragments from the agglomerates, or by smaller fragments recognized in thin sections, may be classified in the order of their abundance as trachytes; analcite-bearing rocks for which the name blairmorite is adopted, and latite. The tinguaite of Knight has not been noted by the present writer,[1] while the latite was not described by the former author. The minerals noted in the specimens include those mentioned by Knight with the exception of acmite, anorthoclase, diopside, and hornblende. Beside these, soda orthoclase (anorthoclase of Knight ?) magnetite, and oligoclase have been noted, and also secondary quartz.

[1]Knight's description of it is added for completeness. See p. 19.

A reddish zeolite, which is almost certainly heulandite, forms druses on some of the joint planes, and occurs also as veinlets in some of the tuffs.

Trachytes—Ægirite-augite trachyte.

This specimen was taken from a boulder about three feet in diameter, which was not found in place. Other rocks of similar appearance are of frequent occurrence in the volcanics, so it may be that the trachyte occurs as a flow in this part of the district. However, microscopic study shows the other specimens that were collected to be pyroclastics, but of such a strikingly similar appearance to this primary type that they were not distinguished as secondary in the field. There is little doubt that a magma of this nature furnished material to form a considerable portion of the volcanics.

The hand specimen (field number 35), shows deep pink, rectangular, and quadratic phenocrysts of feldspar up to an inch long, averaging about half an inch, forming about 20 per cent of the rock, somewhat irregularly distributed in a green, very finely crystalline groundmass which is speckled with shiny, black phenocrysts of pyroxene up to 2 or 3 mm. long.

In thin section the feldspar phenocrysts resemble orthoclase, except that inclined extinctions on 010 up to 14 degrees have been observed. This, in connexion with the absence of twinning and the low index of refraction, indicates that the mineral is soda orthoclase. They are slightly altered, and show kaolinization in cloudy reticulate bands, often obscuring most of the section.

The phenocrysts of pyroxene are idiomorphic or tabular pointed individuals from 0·3 mm. to 1·0 mm. long, showing combinations of the prism and pinacoids in cross section. The extinction angles of $\mathbf{C} \wedge c = 74$ degrees, the grass green colour, and the green to yellow pleochroism determine the mineral as ægirite-augite. Zonal banding is occasionally seen, the centres of some crystals giving a higher extinction than the sides. Twinning parallel to the elongation has been noted. The mineral is remarkably fresh, and the outlines are sharp.

Titanite occurs as phenocrysts in characteristic lozenge shaped, twinned individuals, up to 0·7 mm. long.

The groundmass is apparently not completely crystalline. About 20 per cent of it consists of well-shaped rods of green ægirite-augite up to 0·1 mm. long, embedded in a mass of highly irregular interlocking feldspar grains, somewhat decomposed.

Melanite Bearing Trachyte.

A hand specimen (field number 5) of a breccia of well rounded rock fragments in a tufaceous, green matrix (collected from a bedded series of tuffs and breccias near the base of the volcanics on the West Branch Southfork river, just above Lost creek) shows several pieces of a trachyte containing roughly 40 per cent of tabular red orthoclase phenocrysts, up to half an inch long, embedded in a dense green matrix containing a number of shiny black, dodecahedral melanite phenocrysts. This type of trachyte is frequently observed as fragments in the breccias, and several varieties have been noted.

These rocks are characterized in thin section by large phenocrysts of orthoclase, (in part sanidine) with smaller ones of ægirite-augite, garnet, and titanite, in a groundmass which varies in different specimens, but is characterized by laths of feldspar, doubtless orthoclase, ægirite–augites, and magnetite.

The orthoclase phenocrysts are usually somewhat altered, often show Carlsbad twins, and form up to 40 per cent of the rock.

The pyroxene is up to 0·5 mm. in size, grass green in colour, with a grass green and yellow pleochroism, and occurs as eight-sided idiomorphic crystals. Extinction angles $\mathbf{C} \wedge c$ of 75 degrees have been noted. In some rocks the ægirite-augite is altered to pseudomorphs of matted green scales, mostly chlorite, but is frequently found quite unchanged.

Melanite is usually under two millimetres in diameter, typically idiomorphic and of a yellow to deep brown colour. It commonly has beautiful zonal banding, and occasionally holds small inclusions of aegirite-augite. It is always fresh. The relations of the melanite to the groundmass and to the other phenocrysts, and its manner of occurrence in several types of rocks leaves no reason to doubt its primary origin.

Titanite is a constantly occurring mineral of the trachytes, in fresh, twinned diamond-shaped and rectangular sections up to a millimetre long.

In one fragment a few small phenocrysts of colourless augite were noted. The groundmass of these rocks nearly always has a highly developed flow structure, sometimes in complicated whorls, more often in parallel and sub-parallel arrangements of the minerals. Sometimes the matrix is only partially or very minutely crystallized. No wholly glassy groundmass was noted. A second generation of orthoclase laths is the dominant mineral, with more or less ægirite-augite, often altered to chlorite, and occasional magnetite.

Many trachyte fragments seen only in thin section, contain no phenocrysts, and may or may not represent non-porphyritic varieties. They exhibit several varieties of fine-grained flow structures. As no large fragments of non-porphyritic rocks have been discovered, it is probable that these pieces are from the matrix of a porphyry.

Latite.

This rock (field number 25) is represented by a hand specimen enclosing a portion of a rounded fragment about the size of a man's fist, in a green, tufaceous matrix. It contains pink tabular feldspar phenocrysts, occasionally up to an inch long, averaging about $\frac{3}{16}$ of an inch, forming about 40 per cent of the rock, in a dull green matrix containing small black melanite phenocrysts.

Under the microscope the phenocrysts are seen to be orthoclase and andesine, with smaller titanite and melanite, in a very fine-grained groundmass.

The orthoclase phenocrysts vary from 3 to 10 mm. in the section, and are considerably altered. The andesine phenocrysts are up to 3 mm. in size, also altered, and show albite twinning with narrow lamellæ, as well as Carlsbad twins. Extinction measurements indicate a value of $Ab_{65}An_{35}$ for this andesine. Melanite and titanite occur sparingly, the former up to 1 mm. in size, the latter up to 0·3 mm.

The groundmass is made up of about 50 per cent lath shaped untwinned feldspar, probably orthoclase, the remainder being a formless, isotropic, green substance, perhaps ægirite-augite glass. This latite is an alkaline variety, and clearly related to the rocks with which it is found.

Some small fragments in the thin section cut from field specimen 7, contained small phenocrysts of plagioclase with sharp albite twinning, which seems to be oligoclase, about $Ab_{70}An_{30}$. The groundmass consists of rods of feldspar up to 0·07 mm. long, and a greenish mineral, probably ægirite-augite. Single crystals of oligoclase and andesine occasionally occur in the tuffs, and Knight remarks:—[1]

"From this it may be inferred that parts of the magma from which these clastic rocks were derived had the composition of andesite. The type is quite insignificant, the series as a whole being characteristically trachytic."

The assumption that parts of this magma were as basic as andesite does not seem quite justified by the evidence in hand.

Tinguaite.

Although this variety of rock was not noted by the writer, the description given by Knight[2] is added for completeness:—

"It is a holocrystalline porphyritic rock with phenocrysts of orthoclase (over an inch in diameter) and augite set in a groundmass of orthoclase laths, nephelite, and many ægirite prisms and needles."

Analcite-bearing Rocks.

At least three distinct varieties of these peculiar rocks have been recognized, and others doubtless remain to be discovered. Knight (loc. cit. p. 275) predicted the finding of volcanic rocks of this type, containing analcite phenocrysts, and his suggested locality name, *blairmorite*, has been adopted for the group.

Blairmorite; *Variety A*. This extraordinary rock (field specimen 31) was found as a rounded water worn fragment about two feet in diameter, one of a few similar but smaller

[1]Knight, C. W. Can. Rec. Sci., vol. 9, No. 5, 1905, p. 275.
[2]Idem. p. 274.

boulders in a three-foot stratum of analcite breccia. The matrix in which the boulders are embedded (field specimen 32) is composed of about 40 per cent bright flesh red analcite in icositetrahedral crystals up to an inch in diameter, usually beautifully regular in their crystal form, though often broken. Some crystals are worn nearly to a spherical shape, doubtless by water action. These analcites are embedded in a fine-grained, dull green matrix containing also a number of small dodecahedral melanite crystals. This tufaceous rock has probably a rather similar composition to the magma from which it was derived, which magma is represented by the primary rock fragments now to be described.

Blairmorite, variety A, consists of bright flesh red phenocrysts of analcite up to an inch in diameter, evenly distributed throughout a dark olive green matrix, phenocrysts and matrix each forming half the volume of the rock. Rarely a light pink phenocryst of glassy sanidine is to be observed, and occasional small melanites are present.

The red analcite greatly resembles garnet in the hand specimen, and can be distinguished from that mineral only with difficulty without microscopic or chemical tests.

In thin section the rock is seen to be composed of phenocrysts of analcite in a finely crystalline groundmass consisting of a second generation of analcite, ægirite-augite, nephelite, sanidine, and melanite, which are in turn embedded in an unresolvable matrix, which may be incipiently crystallized analcite, ægirite-augite, etc. Calcite, and perhaps chlorite are the only secondary minerals noted.

The large analcite phenocrysts are faintly pink, homogeneous, and quite isotropic. Cubic cleavage is well developed, and faint, dust-like inclusions are seen along cleavage cracks. Narrow rims of clear analcite border most of the phenocrysts, and this feature is described later under Variety B. Alteration of these large phenocrysts is frequent, and consists of a replacement by calcite, this replacement starting along cleavage cracks and continuing until in some instances the whole mineral is replaced.

The second generation of analcites are much smaller, and rarely exceed 0·3 mm. in diameter. They are yellowish or pinkish, and idiomorphic as a rule, in eight sided or rounded sections, but the edges are not always sharp.

Ægirite-augite occurs sparingly as tabular idiomorphic individuals up to 0·75 mm. long. Some sections exhibit zonal banding and ægirite rims are occasionally found. The ægirite-augite is usually quite fresh.

Nephelite is found in rectangular individuals up to 0·5 mm. long, and is also quite unaltered.

A fresh, clear feldspar with a very small axial angle occurs very rarely, and is thought to be sanidine. Carlsbad twins, up to 0·5 mm. long, have been seen.

Melanite is rare in occurrence, and is of the usual type seen so frequently in these rocks.

There were three rather distinct periods of crystallization during the solidification of this blairmorite. The large analcites grew first to their unusual size on account of the great excess of this material in the magma, and are of intratelluric origin. The second generation of phenocrysts then formed, probably rather rapidly and more or less simultaneously, although relative perfection of outline hints that ægirite-augite, melanite, sanidine, analcite, and nephelite may have been the order. The third crystallization stage was the forming of the matrix, which is only incipiently crystalline.

This blairmorite is remarkable for the large percentage of primary analcite it contains. The size of the larger phenocrysts allowed a measurement of the relative amounts of analcite of the first generation and the groundmass to be made without difficulty. It was found by determinations on several specimens that the surface areas of the larger phenocrysts and matrix were almost exactly equal, so it was concluded that the volume relations were in the same proportion. The matrix, on measurement by the Rosiwal method, was found to contain 50 per cent of recognizable analcite by volume[1]. This gave

[1]The precision of the determination of the proportion of the larger phenocrysts is about 1 per cent; that of the analcite in the matrix probably between 1 and 2 per cent.

a total of 75 per cent by volume for the rock. The specific gravity of the analcite was taken at 2·25, and that of the rock determined to be 2·388. A simple calculation gives 71 per cent as the proportion of analcite by weight recognizable in the rock.

This amount of primary analcite is very exceptional, and marks the rock as an extraordinary type. Percentages of analcite up to 40 are not uncommon in analcite-tinguaites and members of the monchiquite family, and Coleman has described a dyke of heronite from Heron bay, Ontario, which contains 47 per cent analcite.[1]

Up to the present, so far as the writer is aware, this was the highest percentage of primary analcite found in an igneous rock.

Using the 71 per cent of analcite as a guide, the mineral composition of the rock was calculated from the analysis, with the following result:—

Analcite	71	per cent
Ægirite-augite	14	"
Nephelite	5	"
Sanidine	4	"
Melanite	1	"
Titanite	0·5	"
Hematite	1	"
Calcite (secondary)	2	"
Water (free)	1·5	"
	100	

These values are not to be regarded as exact; there is probably, for instance, more analcite than given above, as that represents only the visible, crystallized mineral. There is also some free secondary silica, which was left out of consideration and may amount to 1 or 2 per cent.

The chemical analysis of the blairmorite, as well as of the analcite phenocrysts are given below. For these analyses the writer is indebted to Mr. M. F. Connor, of the Department of Mines, Canada. The analysis of the blairmorite was made

[1]Coleman, A. P., Journal Geology, vol. 7, 1899, pp. 431-436.

from a fresh fragment weighing about 800 grams, all of which was powdered and sampled. For comparison the analysis of blairmorite-tuff given by Knight is introduced here, as well as analyses of other rocks high in analcite.

Analyses of Blairmorite, Blairmorite-tuff, etc.

	I	II	III	IV	V
SiO_2	54·04	54·95	56·75	54·07	52·73
TiO_2	0·20	0·42	0·30	0·15	..
Al_2O_3	18·86	18·64	20·69	21·67	20·05
Fe_2O_3	3·30	4·75	3·52	3·55	3·43
FeO	0·76	1·55	0·59	..	0·99
MnO	0·08	0·34	trace	..	..
MgO	0·70	0·60	0·11	0·36	0·17
CaO	2·32	2·27	0·37	0·36	3·35
Na_2O	9·77	4·91	11·45	8·91	7·94
K_2O	2·26	7·65	2·90	4·76	4·77
H_2O+	7·00 (H₂O+ and H₂O−)	3·35	3·18	5·44	4·85
H_2O-		0·90	0·04	..	0·69
CO_2	0·80	..	..	..	0·93
P_2O_5	..	0·18	..	..	trace
	100·09	100·51	99·92	99·27	99·90
Sp. G.	2·388				

I. Blairmorite, variety A, Collector J. D. MacKenzie, Analyst M. F. Connor.

II. Blairmorite-tuff, Collector W. W. Leach, Analyst C. W. Dickson, Canadian Record of Science, Montreal, vol. 9, No. 5, 1905, p. 276.

III. Analcite tinguaite, Pickards point, Manchester, Mass. H. S. Washington, Am. Jour. Sci., 4th Ser., vol. 7, 1898, p. 185.

IV. Ægirite tinguaite, Hot Springs, Ark., J. F. Williams, Ark. Geol. Surv. 1890, vol. II, p. 370. W. A. Noyes, Analyst.

V. Heronite, Heron Bay, Ontario. A. P. Coleman, Jour. Geol. vol. 7, 1899, p. 435. Analyst, H. W. Charlton.

The analysis of the tuff, column II, resembles that of the primary blairmorite, column I, in a marked degree, differing virtually only in the water content, and in the proportions of the alkalies. The difference almost certainly is caused by relatively more orthoclase in the tuff than in the primary rock. This close agreement in composition is another instance of the similarity obtaining between some of the pyroclastic rocks, in this suite, and their parents, a fact which has been referred to before.

The other analyses given bear a marked resemblance to that of the blairmorite.

The results of the calculation of the analysis of the blairmorite according to the Quantitative System is given below:—

Class, persalane; order, lendofelic, russare; rang, peralkalic, miaskase; subrang, dosodic near persodic, miaskose.

The analysis of the analcite phenocrysts, which were easily obtained free from the enclosing matrix, is given below in column I with some other determinations of the composition of analcite for comparison.

Analyses of Analcite.

	I	II	III	IV	V
SiO_2	54·16	54·39	54·85	57·06	54·55
TiO_2	0·15	..	..	..	..
Al_2O_3	22·35	22·08	22·59	21·48	23·18
Fe_2O_3	0·92	2·85	..	0·13	
FeO	0·06	..	..	..	
MnO	trace	..	..	..	
MgO	0·25	0·27	..	..	
CaO	0·60	0·29	0·89	0·16	
Na_2O	12·49	11·75	12·58	12·20	14·09
K_2O	0·59	1·03	..	..	
H_2O+	8·50	7·97	9·06	8·38	8·18
H_2O-		0·55	..	0·58	
CO_2	0·30	..	..		
	100·37	101·18	99·97	99·99	100·00

I. Analcite phenocrysts from blairmorite, variety A, Collector, J. D. MacKenzie, Analyst, M F. Connor.

II. Analcite from tuff in railway cut west of Coleman, Alberta. Collector W. W. Leach, Analyst C. W. Knight, Canadian Record of Science, Vol. 9, 1905, p. 271.

III. Crofthead, Dana, System of Mineralogy, p. 597.

IV. Secondary analcite, Wassons Bluff, N. S., U.S.G.S. Bull. 207, p. 8.

V. Theoretic composition.

The lime and carbondioxide in the analcite are due to slight replacements of calcite, and are virtually molecularly equivalent. The potassium may be from small inclusions of sanidine, the titanium from inclusions of titanite, and the magnesia from ægirite-augite. The ferric iron is clearly due to hematite, and this causes the red colour of the mineral.

The analysis by Knight, in column II, is almost identical with the one now published for the first time in column I.

The properties of the analcite that have been determined may be briefly summarized here. The colour is flesh red, and the lustre slightly vitrecus; cleavage is fair in the hand specimen, and very well shown in thin section. The mineral is soluble in hydrochloric acid, and on evaporation gelatinous silica results. Before the blowpipe it fuses to a slightly opaque glass, and gives much water in the closed tube. By the immersion method, the index of refraction was found to be greater than 1·466 and less than 1·495, perhaps about 1·48.

Blairmorite, Variety B. This rock is represented by a rather weathered sample (field specimen 21) which was picked up on a ledge of the volcanics, and probably is a portion of a fragment from the breccias. It consists of about 50 per cent pinkish buff analcite phenocrysts, in regular icositetrahedrons up to one-quarter of an inch in diameter, but mostly about one-tenth of an inch. These are embedded in a dull green aphanitic matrix containing occasional phenocrystic specks of dark green pyroxene and black garnet.

The thin section contains symmetrical sections of analcite phenocrysts up to 4 mm. in diameter, mostly between 2 and 3 mm., and some as small as 0·5 mm. Cubic cleavage is highly developed. These phenocrysts are evidently slightly altered, and now show rounded and polygonal light buff areas surrounded by varying sized veins and patches of lighter coloured analcite, the arrangement giving a variegated appearance to the mineral. The deeper buff patches are faintly but distinctly doubly refracting, and the veining is arranged in rectangular directions, suggesting slight alteration (perhaps recrystallization) governed by cleavage directions. Bordering parts of some phenocrysts is a distinct rim up to 0·05 mm. wide of clear, faintly doubly refracting analcite. This rim is in some cases fastened directly to the phenocrysts, in other places being separated by a film of groundmass material; occasionally minerals of the groundmass project into the rim, so its outer boundary is in part gradational. This rim probably represents the groundmass stage of crystallization, during which analcite from the groundmass was added to that already in phenocryst form.

The buff colour of the analcite is due to numerous very minute, dust-like inclusions, which are less numerous in the lighter veining and do not appear in the clear analcite rims.

Some of the phenocrysts are broken, and the fragments displaced by groundmass material.

Besides the analcite, subordinate phenocrysts of ægirite-augite, orthoclase, titanite, and melanite are found.

Ægirite-augite occurs as idiomorphic tabular forms up to 1 mm. long, twinned in some cases, and quite fresh. It resembles ægirite-augites previously described.

Orthoclase is found sparingly as tabular crystals up to 0·6 mm. long. They show Carlsbad twinning, and are clear and unaltered. Along the sides, for a distance of 0·03 mm. inside the crystal are microlites of augite and apatite(?) orientated parallel to the sides of the crystal. They give the appearance of successive stages in crystal growth, and are probably analogous to the rims on the analcite phenocrysts.

The melanite phenocrysts are about 0·3 mm. in diameter, and are similar to the other occurrences of the mineral, exhibiting irregular cleavage, zonal banding, etc.

Titanite occurs as typically lozenge shape and also tabular twinned crystals up to 0·75 mm. long.

The groundmass is very fine grained, and consists of laths of orthoclase, up to 0·1 mm. long, the larger showing Carlsbad twins. These laths are diversely or fluxionally arranged, often subparallel to the outlines of the phenocrysts, and make up about 40 per cent of the groundmass. Ægirite-augite, also about 40 per cent of the matrix, forms small, irregular grains up to 0·03 mm. and interstitial to the orthoclase. Analcite forms the major part of the remaining 20 per cent of the groundmass, in shapeless grains up to 0·03 mm. in diameter. The groundmass contains numerous microlites in the shape of colourless rods up to 0·2 mm. long, which are probably apatite. A measurement of the amount of analcite in this rock has not been made. It is estimated at about 60 per cent. Analyses of this rock are not available.

Blairmorite, Other Varieties. Besides the two distinct varieties of blairmorite just described, other specimens occur as fragments recognized only in thin section as analcite bearing rocks. They are all fine-grained rocks and may be portions from the matrix of porphyritic types, as A and B. The mineral associations are analcite, orthoclase (or sanidine) ægirite-augite, melanite, titanite, etc. No hand specimens of these rocks have been collected. It is to this variety of analcite trachyte that the name blairmorite was applied by Knight. The individuality of varieties A and B almost renders them worthy of distinctive names, but the rarity of the type, and their assured variation, in spite of their unique family resemblance, together with the vagueness of Knight's definition, decided the writer to adopt the name blairmorite for these analcite-bearing rocks.

Blairmorite may be redefined as a primary porphyritic volcanic rock, characterized by dominant phenocrysts of analcite in a matrix composed of analcite, alkali feldspar, and alkali-pyroxene, with titanite, melanite, and nephelite, not all of these groundmass minerals being necessarily present, and possibly others occurring. The rock on account of its ultra-alkaline nature will show numerous variations in texture and in proportions of component minerals, and the above definition has not been made more rigid on that account.

Alteration. These primary rocks are very slightly altered. Much of the feldspar is kaolinized, but not to any great extent, and a large amount of clear glassy sanidine and orthoclase is found. Ægirite-augite is usually quite unaltered, though some of it is changed to chlorite. The analcite is slightly changed in some specimens, and a replacement of this mineral by calcite occurs in varying degrees up to completion. Alteration of melanite has not been observed. Such changes as have taken place are those characteristic of the zones of weathering and oxidation, and no secondary minerals characteristic of the deeper zones are present.

SECONDARY ROCK TYPES. (PYROCLASTICS).

Preliminary Statement.

The scope of the present paper does not admit of a detailed description of the many varieties of agglomerate and tuff studied in thin section. Certain types are peculiar, or are repeatedly found, and these merit a word of description.

The lithologic terms used here in describing the pyroclastic rocks should perhaps be defined, as there seems to be some disagreement as to the exact meaning of the words tuff, agglomerate, and breccia. *Tuff* in this paper denotes a stratified deposit of the finer volcanic ejecta, of the general size of grain of sandstones. The coarser varieties are termed *agglomerates*. *Breccia* is used only to mean "broken rock," as it is a term of too general application to be applied to a single class of deposits without some qualifying adjective. Even in the latter case it is not necessarily definitive, as a wide variety of pyroclastic rocks, of differing textures and origins, may properly be spoken of as volcanic breccias.

As in the case of sandstones and conglomerates, there is an intimate gradation between tuffs and agglomerates, and the varying proportions of fragments of different sizes precludes the possibility of rigid definition. In this paper, stratified pyroclastic rocks having fifty per cent or more of their fragments great than six millimetres (one-fourth inch) are termed *agglom-*

erates, and rocks of finer grain than this are termed *tuffs*. The definition is arbitrary, and the dividing line of size may not be agreed to by all, but the reader will at least know the general textural appearance of the rock from the name applied to it. It will be recognized that tuffs as here defined are rocks much in appearance like sandstones, while agglomerates, with their coarser grain, simulate conglomerates texturally. A rock like specimen 39, described below, containing several fragments of feldspar up to an inch in diameter, embedded in a fine tufaceous matrix, is here called a tuff, owing to the predominance of very fine material. Its analogue in the detrital sediments may be taken as a pebbly sandstone, but there are objections to the term "pebbly tuff."

Orthoclase Tuff.

Constantly recurring in the exposures of the volcanics are rocks in appearance greatly simulating porphyries, and at first mistaken for flows in the field. They are alike in containing rectangular crystals and broken fragments of orthoclase (sometimes soda orthoclase and sanidine) up to an inch long, embedded in a fine tufaceous matrix, whose clastic character is sometimes only certainly determined by the microscope. The resemblance between specimen 39, a soda orthoclase tuff, and specimen 35, an ægirite-augite trachyte, is particularly striking, in colour, size, and, to a great extent, shape, of the phenocrysts, and also in the colour and texture of the matrix. Specimen 87, a sanidine tuff, is also remarkably like a porphyry in the hand specimen, and numerous other cases have been observed in the field.

In the case of the two rocks just mentioned, it is thought that the ægirite-augite trachyte magma, on explosion gave rise to the soda orthoclase tuff. The question may be raised as to why the pyroclastic rock is not called ægirite-augite tuff, in conformity with its parent primary type. In the case of the trachyte, ægirite-augite is the definitive mineral, distinguishing it from other trachytes, while in the case of the tuff, soda orthoclase is the distinctive mineral of the rock.

Sanidine Tuffs.

These are usually fine, even-grained, light greyish green to dark green rocks, in many cases indistinguishable from sandstone (and even from traps) in the field. Occasionally specks of glassy feldspar or melanite are seen, and even of fine-grained rock fragments.

In thin section the rocks are characterized by a large amount of sanidine, mostly less than 1 mm. in diameter, and quite angular. The matrix is very fine, not clearly resolved by the microscope, and probably consists of finely comminuted feldspar, pyroxene, analcite, etc.

Blairmorite—Agglomerate.

This is another instance of a pyroclastic rock closely simulating the crystallized representation of its parent magma. Forming the matrix in which the large fragments of blairmorite (variety A) were found, is a clastic volcanic rock, consisting of about 40 per cent of analcite crystals and fragments, wholly separated from their groundmass, which are embedded in a greenish fine to medium tufaceous matrix composed of small fragments of dense greenish rock, with other pieces of white orthoclase and many black garnets (melanite). Some portions of this agglomerate are strikingly like the blairmorite in appearance, owing to the size and proportion of the bright red analcite crystals and fragments.

An analysis of the blairmorite tuff described by Knight is quoted on p. 23. There is, of course, no very exact similarity among the various blairmorite pyroclastics in regard to ultimate composition.

Tuffs and agglomerates of various other sorts are found, but all are characterized by different association and proportions of the rocks or minerals already described. Many of the pyroclastic rocks are largely replaced by calcite, and the various stages of replacement are very interesting.

DISCUSSION.

Aside from their exceptional petrographical composition these volcanics are interesting from other standpoints. They are only one of the few post-Cambrian bodies of igneous rock in the great geosyncline of the Rocky Mountain system in Canada. Igneous rocks, abundant in the more western Cordillera, have been found so rarely in the Rocky mountains of Canada as to excite particular interest. Farther south, in Montana, volcanic rocks, also of alkaline types, occur, intruding strata of late Cretaceous age[1].

In the Ice River district, British Columbia, are found ultra alkalic igneous types also, here consisting of a complex of plutonic rocks in the form of an asymmetrical laccolith.[2] The age of this intrusion is placed as post-Cretaceous, on structural and correlation evidence.

These instances of plutonic and hypabyssal rocks of post-Cretaceous date, of similar highly alkaline types, are significant when correlated with the mid-Cretaceous Crowsnest alkaline volcanics.

In the well known "Petrographic Province of Central Montana" described by Pirsson,[3] the rocks are characterized by equal amounts of soda and potash in the most siliceous types, with potash increasing in the less siliceous types. Although only one analysis of the Alberta rocks is available, the petrography leaves no question that soda in this area greatly dominates over the potash. As the Crowsnest volcanics form only a single occurrence in a localized area, they cannot be considered as forming a petrographic province by themselves. Taken in connexion with the numerous other alkaline occurrences in the Rocky mountains of the United States, many of which are referred to in Pirsson's paper,[4] they serve to extend the alkalic

[1]Pirsson, L. V. Bull. U. S. Geol. Survey No. 237, p. 199, and map, p. 20.

[2]Allan, J. A. Geology of the Ice River district, B. C.: Abstract of a thesis presented to the faculty of the Massachusetts Institute of Technology in partial fulfilment of the requirements for the degree of Doctor of Philosophy, 1912, p. 4, etc.

[3]Pirsson. L. V. American Journal of Science, 4th ser., vol. 20, 1905, pp.35–49.

[4]Loc. cit. p. 36.

petrographic province farther north and form an areal link between the rocks of Ice river, B.C., and those of Montana.

It is suggested that this international area characterized by alkalic rocks of widely varying types, from the nalsic blairmorite to the mafic analcite basalts, for instance, be termed the Rocky Mountain Petrographic Province.

This large area, characterized on the whole by alkaline rocks, and containing subdivisions which form smaller petrographic provinces, illustrates the idea that the regional progression of types, first mentioned by Pirsson[1] by which he means the varying relative distribution of types among different localities in the same province, may be extended to include the "regional progression of petrographic provinces." Just as any individual province is characterized from place to place by varying related individual rock types, so the larger petrographic provinces may be characterized by varying related individual provinces. Iddings states virtually this same idea in the form of a question in volume two of his work on "Igneous Rocks."[2]

It is perhaps worth reiterating that the Rocky Mountain alkaline province is in sharp contrast with the even more extensive subalkaline province of the northern Coast ranges of the Cordillera.

The earlier age of the volcanic rocks which are here described is compatible with the generally accepted sequence of igneous action; first volcanic, then plutonic, and lastly dyke phases. Pirsson,[3] infers that the time of igneous activity in the Highwood mountains was coincident with the general geologic disturbance at the close of the Cretaceous and in the early Tertiary.

The stratigraphic position of the Crowsnest volcanics may be evidence that the first tectonic disturbances of the Laramide revolution took place in Alberta in mid-Cretaceous time. After these first uneasy stirrings of the earth's crust, a period of subsidence and quiet ensued, before the final upheaval began, that culminated in the folding and uplift of the Rocky Mountain

[1]Loc. cit p. 48.

[2]Iddings, J. P. Igneous Rocks, Vol. 2, John Wiley & Sons inc., N. Y., 1913, p. 467.

[3]Pirsson, L. V. Bull. U. S. Geol. Survey No. 237, p. 199.

geosyncline. During this revolution, the Highwood laccoliths, and the Ice River laccolith were intruded.

SUMMARY AND CONCLUSIONS.

The Crowsnest volcanics consist of fragmental stratified pyroclastic rocks which exhibit several primary types occurring as fragments. These are, in order of abundance, trachytes, blairmorites, and latites. Tinguaite has been described by C. W. Knight[1] as also occurring. The trachytes are soda-rich varieties, and ægirite-augite trachyte, and melanite trachyte have been recognized as separate types. The blairmorites are unusual rocks, ultra alkaline, soda-rich porphyries characterized by primary analcite in large quantities up to 71 per cent. The primary types have been altered only slightly.

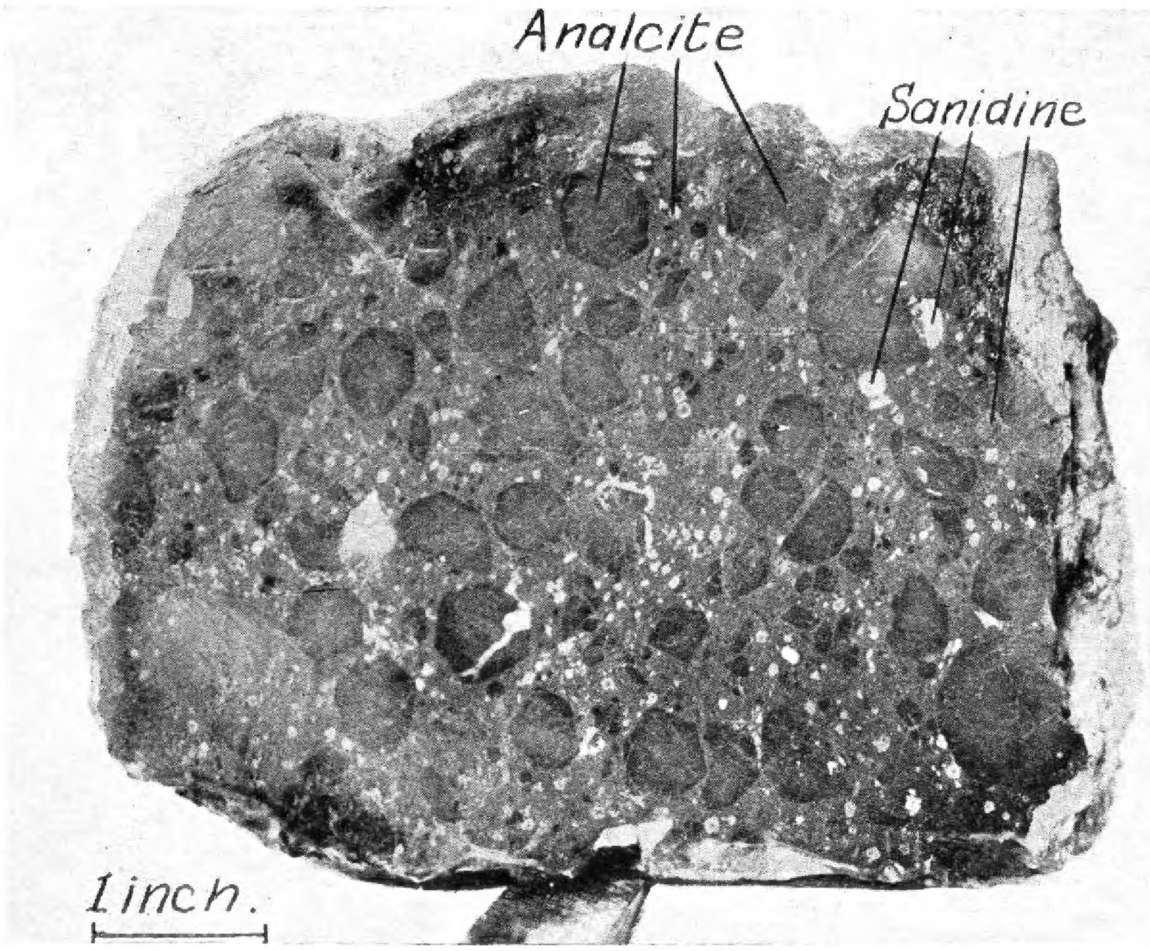
The fragmental volcanic rocks consist of both mineral and rock fragments of varying sizes and associations, characterized by minerals typical of alkaline rocks, orthoclase, sanidine, soda orthoclase, ægirite-augite, analcite, melanite, titanite, etc.

This occurrence of alkaline rocks between the well-known Montana alkaline localities, and the ultra alkaline intrusive mass of Ice river, B. C., forms a link in the chain of alkaline rock bodies occurring in the front ranges of the Rocky mountains, and the rocks of general region are considered to form a related group to which the name of the Rocky Mountain Petrographic Province is given. Inside of this large province, the relations of the individual provinces are compared to the relation of single types in any given province.

[1]Knight, C. W. Canadian Record of Science: vol. 9, No. 5, 1905, p. 274.

Explanation of Plate I.

Blairmorite, variety A.


Analcite
Sanidine
1 inch.

The first number of the Museum Bulletin was entitled, *Victoria Memorial Museum Bulletin Number 1.*

The following articles of the Geological Series of Museum Bulletins have been issued.

Geological Series.

1. The Trenton crinoid, Ottawacrinus, W. R. Billings; by F. A. Bather.
2. Note on Merocrinus, Walcott; by F. A. Bather.
3. The occurrence of Helodont teeth at Roche Miette and vicinity, Alberta; L. M. Lambe.
4. Notes on Cyclocystoides; by P. E. Raymond.
5. Notes on some new and old Trilobites in the Victoria Memorial Museum by P. E. Raymond.
6. Description of some new Asaphidæ; by P. E. Raymond.
7. Two new species of Tetradium; by P. E. Raymond.
8. Revision of the species which have been referred to the genus Bathyurus (preliminary paper); by P. E. Raymond.
9. A new Brachiopod from the base of the Utica; by A. E. Wilson.
10. A new genus of dicotyledonous plant from the Tertiary of Kettle river, British Columbia; by W. J. Wilson.
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